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Green waste to biogas: Renewable energy possibilities for Thailand's green markets

Ghaffar Ali [a,*], Vilas Nitivattananon [a], Sawaid Abbas [b], Muazzam Sabir [c]

[a] School of Environment, Resources and Development, Asian Institute of Technology, Khlong Luang, Pathumthani 12120, Thailand
[b] Remote Sensing and Geographic Information Systems, Asian Institute of Technology, Thailand
[c] Department of Agriculture Economics, University College of Agriculture, University of Sargodha, Sargodha, Pakistan

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ABSTRACT

Today, the production of energy from waste is not a new process; however, its implementation and application continue to be a challenge in developing countries. Despite the abundance of valuable waste in the urban markets of these countries, practices aiming at renewable energy generation are missing. In Thailand, so-called green markets are replete with renewable energy potential, but the practical implementation of this potential is rare. Therefore, the main purpose of this study is to show that the conversion of green waste into renewable energy is not only environmentally beneficial but also financially rewarding. This is demonstrated by exploring the energy potential of the market and conducting a benefit–cost analysis under two scenarios. The results illustrate that for the selected market, converting organic waste into biogas is advantageous both environmentally as well as financially; further, the benefit–cost ratio is three times higher after conversion, compared to before. Additionally, there is a huge margin of conversion and production of biogas. The policy makers and planners of Talaad Thai (Thailand's largest green market) should invest greater effort in initiating plans, and set an example for other markets in Thailand, in order to make this planet clean and green.

Contents

1. Introduction

Developing countries in Asia are currently faced with problems such as increasing urbanization and demands for more food and shelter to sustain a standard life pattern. Organic waste is primarily composed of food, especially in the mega cities of Asia, such as Tokyo, Beijing, Bangkok, Seoul, Karachi, Mumbai, and Colombo. All these cities are facing solid waste problems because of an increasing population, urbanization, and the ultimate demand for more food. Solid waste mismanagement is one of the main reasons for environmental deprivation, especially in developing countries. The complex interrelationship between the environment and trade has become a focal point for both national policy makers as well as international ones. Statistical data from the International Energy Agency [1] shows that conventional energy resources like oil continue to be the most important sources of energy, accounting for approximately 80% of the total primary energy supply (TPES); oil is followed by coal and gas as sources of energy. The second-most important contributor is combustible renewable energy (CRE), which accounts for 10% of the world's TPES share. CRE, or traditional biomass energy, constitutes 80% of the total renewable energy consumed mainly

* Corresponding author. Tel.: +66814892997.
E-mail address: ghafar.gs@gmail.com (G. Ali).

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in developing countries [2]. In recent years, countries around the world have turned their attention to renewable energy options in light of the ever-increasing load of energy demand, soaring oil prices, and uncertain resources for conventional power generation, in addition to the well-known adverse effects of oil on climate and human health [3]. The "four energy paths" – developed by the Enquete Commission – are typically taken into account in order to attain sustainability with existing and alternative resources of energy. These energy paths are as follows. Path 1: continuation of current energy use technologies with amendments; Path 2: universal adoption of advanced energy technologies for transportation and electricity generation; Path 3: the production of alternative renewable energy sources from waste and biomass resources to supplement conventional energy production processes; and Path 4: the development of centralized clean energy production routes and distribution systems [4].

The fruit and vegetable markets produce large amounts of waste each year, and the disposal of these wastes is costly, both financially and environmentally. Studies [5–14] have revealed that by utilizing the physiochemical properties of these wastes, they can be upgraded to products of higher value that have a place in the market. Vegetables, fruits, and flowers are sold in large quantities in markets, and wastes thereof are disposed of along with municipal solid wastes (MSW) in landfills or dumpsites; this creates a breeding ground for vector, pest, odor, and greenhouse gas (GHG) emissions into the atmosphere. Renewable waste materials from agriculture, industries, and domestic sources are converted to useful energy forms such as biohydrogen, biogas, and bioalcohols through waste-to-energy routes for global sustainable growth.

Studies around the world, and particularly in Asia [15–20], have focused on energy production from MSW obtained from cities like Thailand and counties at different levels. Other studies [21–25] have focused on the aerobic digestion of wastes from different sources, and still others have considered the industrial sector for the conversion of waste into energy solutions. However, none of these studies have taken into account the use of green market wastes to regenerate energy and/or biogas. Despite their fragile nature, products from green markets are less perishable and have immense potential for energy production, especially biogas.

There is great future for the fruit and vegetable markets, the so-called green markets, of Thailand to produce renewable energy from green waste. If this waste is properly utilized, it could contribute immensely to the energy needs of the markets themselves and to associated departments as well. Therefore, in this study, we take a preliminary, yet challenging, step to conduct research on the green markets in Thailand. The main aim of this research is to review the potential of producing biogas from the waste generated in order to show that the conversion of waste is environmentally friendly; we also conduct a benefit–cost analysis (BCA) to show that the production of biogas is cost-effective as well.

This paper is divided into six main parts: the introduction; Thailand's energy consumption and emissions; a case study of Thailand's largest market; renewable energy potential; BCA; and the conclusions.

2. Thailand's energy consumption and emissions

Thailand is one of the emerging economies of Southeast Asia, with a population of almost 69 million according to the 2010 World Bank report [26,27]. In Thailand, recycling is widely accepted as a sustainable MSW management method. This method is attractive for local government authorities (LGAs) because of its potential to reduce disposal costs and waste transport costs, and prolong the life spans of sanitary landfill sites [28]. Traditionally, the municipal authorities and contracted waste collection companies have been responsible for waste management in cities. However, the waste management problem has already become so severe in most cities that municipal authorities alone are unable to cope with the needs and demands for the collection and disposal of wastes. Some of the common waste management problems in developing countries include institutional deficiencies, insufficient resources, absence of proper collection systems, lack of environmental awareness, and unwillingness on the part of the public to participate and cooperate in solid waste management [29].

Solid waste generation in developing and least developing countries (LDCs) is increasing by the day [30]. Fig. 1 illustrates the solid waste generation in developing countries and LDCs; it is obvious from this figure that the generation of solid waste in LDCs is higher than it is in industrialized and emerging countries such as Thailand. This could be due to tourism, rapid urbanization, construction, and/or population density in LDCs. Thus far, Thailand's per capita generation of waste per day is higher than those in other developing countries, and Cambodia has higher waste generation compared to other LDCs.

The energy consumption levels, patterns, and growth rates in developing countries are higher than before. Urbanization and industrialization boost energy usage as well as GHG emissions from different activities. Table 1 and Fig. 2 list the primary commercial energy consumption and CO_2 emissions from energy consumptions from 2005 to 2010, respectively, in Thailand.

3. Case study of Thailand's largest market

Talaad Thai, Thailand's largest integrated agricultural wholesale market, is located in Klong Lunag district in the Pathumthani province of Thailand, within the boundary of the Bangkok Metropolitan Region (BMR). It was established in 1995 and is managed by Thai Agro Exchange Company (TAECO) Ltd. "Talaad" in Thai means "market," and "Talaad Thai" therefore means "market of Thailand." This market is approximately 500 rai[1] (200 acres), and is home to the distribution center for domestic and international agricultural products, especially fruits and vegetables. Talaad Thai has 24 h high-quality infrastructure including security; 6 main lanes, each 30 m in width; concrete parking spaces; three modern food centers; 7-Eleven stores; banks; and shopping facilities for commodities other than fruits and vegetables. The reason for constructing such a huge marketplace in the center of the country was to provide access to everyone, from sellers to consumers, and to have one window operating system for all farmers, wholesalers, and buyers. Talaad Thai is managed and run by TAECO Ltd., a private company, and they maintain strict confidentiality about their structural setup, planning, and procedures in order to avoid competition, because they consider being number one as key to their success. Located in Talaad Thai is the Perishable One Stop Service Export Center (POSSEC), a government co-operative that provides the timely export of fruits, vegetables, and flowers; this center is entrusted by the government under the supervision of the department of Internal Trade, Ministry of Commerce, Thailand. Talaad Thai functions well from a business point of view; it is the largest and most popular market in Thailand. However, environmental operations in this market are not standardized and up-to-date. There is lack of waste management within the market, despite its

[1] Rai is a land measurement scale used in Thailand; 1 rai = 0.4 acres.

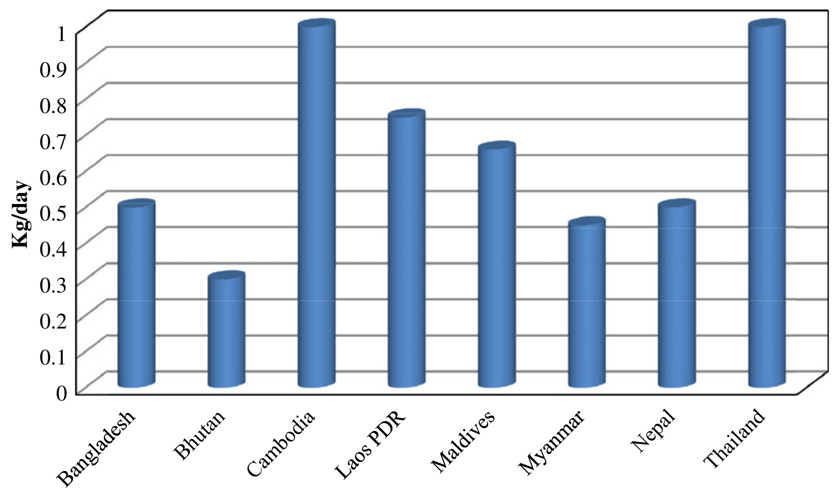


Fig. 1. Solid waste generation rate per capita of Asian countries [30].

Table 1
Primary commercial energy consumption of Thailand [31].

Types of energy	2005	2006	2007	2008	2009	2010
Petroleum (M.Liters)	689	674	667	634	643	655
Natural gas (MMSCF)	566	579	615	648	682	693
Lignite (Tonnes)	125	108	99	101	98	100
Coal (Tonnes)	107	140	180	199	205	212
Hydro/imported electricity (GWh)	33	44	43	36	35	37
Total	1520	1545	1604	1618	1663	1697
Growth rate (%)						
Petroleum	0.4	−2.3	−1	−5	1.4	1.6
Natural gas	9.2	2.3	6.2	5.4	5.2	5.5
Lignite	4.2	−14	−7.8	2.4	−3.4	−3.0
Coal	13.8	30.9	28.5	10.6	2.9	3.1
Hydro/imported electricity	2.4	35.2	−2.5	−17.4	−1.1	−5.9
Total	4.8	1.6	3.8	0.9	2.8	2.5

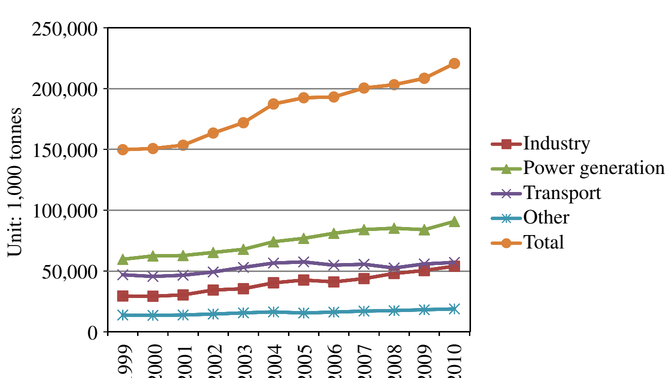


Fig. 2. CO_2 Emissions from energy consumption of Thailand by sector [31].

abundant potential to produce renewable energy from organic waste. The current waste management system and processes are displayed in Fig. 3.

This figure plots the route from the waste generation points to the disposal sites, and it can be noticed that almost no recycling takes place: approximately 85% of organic waste is generated per day in the market, of which over 90% is dumped into landfills. In this study, Talaad Thai will be used to set an example – for waste-to-energy options – to other smaller markets that have the potential to produce biogas, albeit to a smaller extent.

4. Renewable energy potential

Talaad Thai generates 120 t of waste per day, of which almost 85% is organic and hence suitable for use in renewable energy, especially biogas production. An analysis of the market's solid waste generation data reveals that organic waste constitutes the major portion of the total waste (more than 85%), of which about 74% is vegetable and fruit waste, 8% is food waste, and 5% is waste from the flower market. Therefore, the bulk of waste comprises green products. Fig. 4 depicts the composition of waste generated in Talaad Thai, and Table 2 explains the chemical properties required for the production of biogas. It is evident from Table 2 that the carbon-to-nitrogen (C:N) ratio of the waste from Talaad Thai is highly suitable for the production of biogas. The chemical properties of the waste are also favorable for biogas production.

Unfortunately, all the organic waste from Talaad Thai – except for a few kilograms of vegetable leaves (which are sold to the local people as animal feed) – is dumped into landfills. Although Talaad Thai does not own any landfill sites, the management contracts private landfill sites situated almost 60 km away from the market. Nearly 150 people are engaged

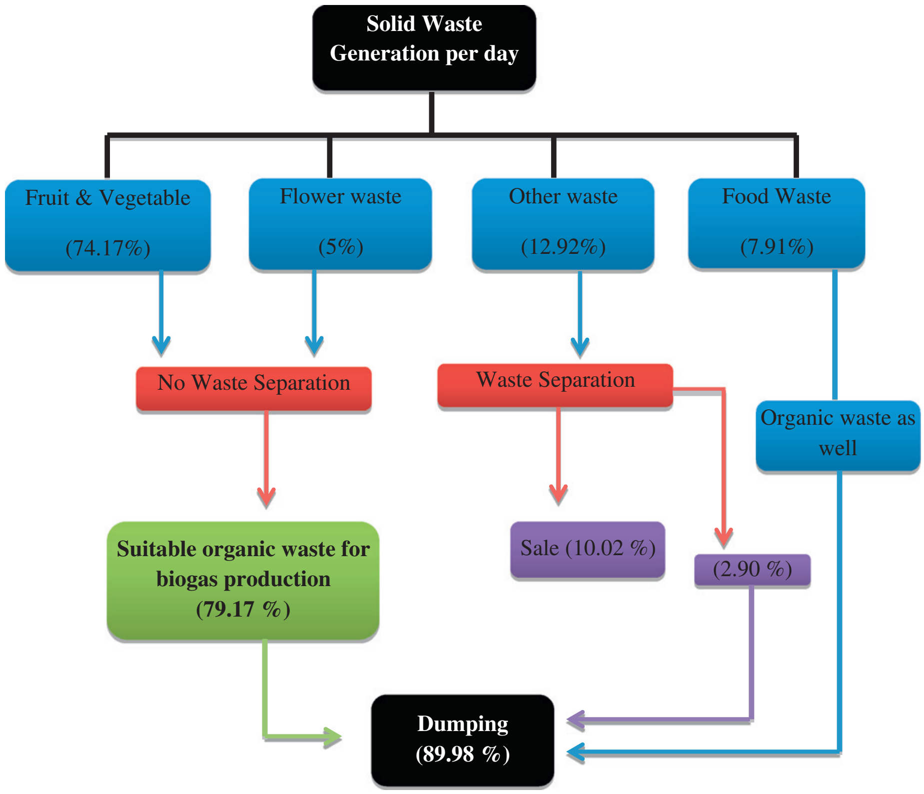


Fig. 3. Current solid waste management system in Talaad Thai [32].

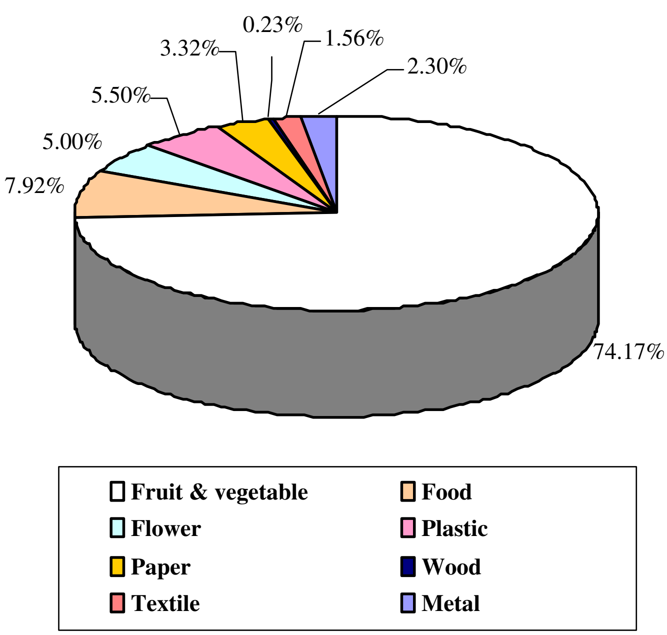


Fig. 4. Solid waste composition of the market [33].

in cleaning, collecting, and disposal. Similarly, a total of 12 trucks are appointed for waste handling from the market to the Bangsai disposal site (in another province). From the 12 trucks, 6 are used for the collection and transfer of waste within the market itself, while 6 are used for outside transfer, that is, for transporting solid waste from the market to a disposal site in Ayutthaya province [12]. In this way, 90% of the waste is dumped in the landfills without so much as a deliberation

Table 2
Chemical properties of the market's organic waste [34].

Properties	Organic waste
Bulk density (gm/cc)[a]	0.4–0.6
Moisture content (%)[a]	89–90% (decreases upto 50–60%)[b]
Dry matter (%)	7–11
pH	4.0–5.5
C/N ratio	**21–25 (increase to 30–35%)**[c]

[a] Wet basis.
[b] Dry basis.
[c] After separation.

about recycling or reusing it. Every year, almost Thai baht (THB) 10 million is allocated for the cleaning and disposal of waste generated in Talaad Thai. If the same money were spent on installing energy production plants, profits would increase and the burden on the environment would reduce. In the following section, we conduct a BCA to determine whether converting waste into biogas is profitable from a business perspective.

5. Benefit–cost analysis (BCA)

In order to achieve the objectives set at the start of this study, a benefit–cost ratio (BCR) analysis is conducted to investigate whether the conversion of waste into biogas is beneficial to the environment and financially feasible. BCA is a technique for evaluating a project or investment by comparing its economic benefits with the economic costs associated with the activity. Finally, BCA aims to examine potential actions that aim to improve social welfare [28]. Several variations of the basic benefit–cost rule can also be used to compare the benefits and costs of investments, projects, or decisions.

For better understanding, this analysis is explained from the perspective of two situations: the existing scenario and the proposed scenario. BCAs have been used in many studies [29–32] for a variety of reasons; however, they are very rare in studies on biogas production. Therefore, BCA has been adapted from other researches [35–37,40–42] and is also widely accepted in economic-cum-environment studies. In this study, two situations are described: existing and proposed. All the input costs used — labor cost, capital and machinery costs, skilled labor cost, etc.—are in accordance with the current market prices in Thailand.

The following simple formulas were used for the calculation:

$$\text{Gross return} = \text{Total benefits} - \text{Total costs}$$

The BCR is calculated as the total benefits divided by the total costs:

$$\text{BCR} = \frac{\sum_{r=1}^{r}(B_t/(1+r)^t)}{\sum_{r=1}^{r}(C_t/(1+r)^t)}$$

Then, the return period for investment cost was also calculated by the following formula:

$$\text{Return period for investment cost} = (\text{Investment cost}/\text{Return benefit})/\text{Year}.$$

5.1. Existing scenario

Currently, the Talaad Thai solid waste management department invests around THB 10 million annually for all activities performed—cleaning, collection, transferring, and transportation to disposal sites. This constitutes a firsthand investment that the waste management department has been undertaking for the past 10 years [33]; however, they get nothing in return, even after having access to so much useful waste in their own market. The installation of biogas plants will be cost beneficial because the cost of separation, transportation, labor, landfill, and other contracts will be reduced by more than half the existing cost, that is, THB 8030,000 per annum. This is the firsthand benefit of discontinuing the transfer and dumping of waste. Table 3 explains the current scenario of solid waste generation and the benefits to be obtained by discontinuing the dumping of green waste (if adaptation takes place).

Table 3
Benefit–cost analysis in current scenario.

Total cost invested for SWM per annum	Total benefits	Savings by not dumping the waste at first hand	
~10 million	Nil	Unit cost per ton	220
		Total quantity (tonnes)[a]	100
		Total cost per day	22,000
		Total direct savings per annum	**8030,000**

[a] Only 20 t will be dumped out of 120 t per day.

5.2. Proposed scenario

A BCA is proposed for a biogas plant. Generally, different types of costs are involved for the set up of any biogas plant; all these investment costs depend entirely on the size of the plant, the technology adopted, and labor costs. In the case of Talaad Thai, we propose a biogas plant with a single-stage wet system, with a carrying capacity of almost 1000–110,000 t of waste annually. Specifically, the biogas production technology works on anaerobic digestion (AD). The process of AD to produce biogas is quite common, and although it varies from country to country, it is well understood in the research community. The number of plants would depend on the amount of waste generated in the market, and this would be a single stage system especially for green waste. The single-stage wet system performs optimally at 35 °C or 95 °F, which best suits the climate in central Thailand. Furthermore, total solid contents (TSC) could be more than 20% in this case [38,39,43,44]. To make the proposal clear and focused, the total investment cost was broken down into a few major categories. The foremost requirement for the installation of a biogas plant is land; a specified piece of vacant land is required, which Talaad Thai already has (there remains some vacant space within the vicinity of the market); thus, the cost for land purchase is equal to zero and not included in the proposed scenario. The remaining costs are for construction, process equipment and machinery, working capital and contingency, and fees. In total, the total investment cost for setting up a biogas plant is approximately THB 4 million.

Based on the current market price of THB 12 per kilogram, the unit cost of biogas production is THB 12,000 per ton, and the total amount of organic waste is 100 t per day. However, the convertible amount, which is best suited for the biogas plant after separation and cleaning, is around 29.4 t per day because of the volatile solid property of organic waste. Therefore, the final amount of biogas in hand will be approximately 15 t per day.

The benefits of setting up a biogas plant are now clear, and by adopting this technique, almost THB 8 million can be directly saved in transferring, labor, transportation, and landfill fees. Further, yearly costs for operation and maintenance account for approximately 20% of the annual profit; this accounts for nearly THB 1 million, which is more than 80% net profit. The BCR is three times higher than the standard ratio acceptable for this analysis. Further, setting up a biogas plant does not require much labor and heavy manual work. There is also no need to market biogas as it is already in demand and is a need of almost every individual. Moreover, this is also an environmentally friendly product that will directly reduce waste problems for the market, and place less burden on land use and emissions. Return on investment will take approximately only two years once the plant starts production, as

Table 4
Benefit–cost analysis in proposed scenario.

Investment cost[a]		Operation and maintenance cost		Benefits	
Construction	1000,000	Unit cost per ton	2500	Unit cost per ton	12,000
Working capital & contingency	1000,000	Total waste quantity (tonnes)	29.4	Total biogas quantity (tonnes)	15.1
Process equipment & machinery	1500,000	Total cost per day	73,500	Total income per day	181,200
Fees[b]	500,000	Total cost per annum	**882,000**	Total benefits per annum	**2174,400**
Total	**4000,000**				

[a] All figures are given in Thai baht (THB)
[b] Fees of local consultants, bio-works and authority submissions etc.

the profit margin is higher than of current situation. The entire calculation of the BCA is explained in Table 4.

Total cost of biogas per annum = THB 8,82,000

Total benefits from savings and biogas production
= THB 803,000 + THB 2174,400
= THB 2977,400

Gross return per annum = Total benefits − Total costs
= THB 2,977,400 − THB 8,82,000 = THB **2,095,400**

BCR = Total benefits/Total costs
= 2,977,400/8,82,000 = **3**.37

Investment cost for biogas plant = THB 4000,000

Return period for investment cost
= Total investment cost/Net return per annum
= 4000,000/2095,400 = ~**2 years**.

6. Conclusion

This study was part of a preliminary effort to review the energy potential of green markets. This task was challenging because it was the first of its kind; studies on the renewable energy potential of green markets, especially in Thailand, are rare. Consequently, it was quite difficult to compare the results of this study to those of other studies, although this could serve as a benchmark and open up avenues for further research in this field. The results of this study showed that compared to dumping waste into landfills, the conversion of these wastes into biogas is a better solution as the Talaad Thai market has immense potential to produce renewable energy. Sustainable waste management will serve as the main benefit for the whole market, and financial profits will serve as a co-benefit. A biogas plant is not only an environmentally friendly way in which to manage waste but it can also help reduce the financial burdens on the market; this makes it the ultimate solution. The BCR showed that profits will be three times higher than routine profits. Hence, we can state that converting waste into energy is not only a sustainable solution for waste management but is financially rewarding as well. The Talaad Thai management needs to alter their policy framework and deliberate on the conversion of waste into renewable energy options, which is not only the better solution for the market but also a more sustainable solution for the BMR, and ultimately, the entire country. If the Thailand's largest market can serve as an example to smaller markets by implementing renewable energy practices, then these markets will soon follow suit, leading to sustainable waste management and the best renewable energy options for Thailand.

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